A Pulse-Current Implementation Using Phase-Shift Modulation in Smart Battery

Huang, Xinrong; Acharya, Anirudh Budnar; Stroe, Daniel-Ioan; Teodorescu, Remus

Published in:
PCIM Europe digital days 2020; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, Germany, 2020

Publication date:
2020

Document Version
Accepted author manuscript, peer reviewed version

A Pulse-Current Implementation Using Phase-Shift Modulation in Smart Battery

Xinrong Huang[1], Anirudh Budnar Acharya[1], Daniel-Ioan Stroe[1], Remus Teodorescu[1]

[1] Department of Energy Technology, Aalborg University, Denmark

Corresponding author: Xinrong Huang, hxi@et.aau.dk

The Power Point Presentation will be made available after the conference
(mandatory for oral speakers).

Abstract

Pulsed current provides a rest-time for battery cells to fully complete internal chemical reactions that can suppress the increase of resistance to extend the battery lifetime. This paper proposes a new method to implement pulsed current using synchronized/unsynchronized Phase-Shift Modulation during both charging and discharging processes in a smart battery management system. Faulty cells can be permanently bypassed without any impact on the architecture of the Smart Battery. Simulation and experimental results verify the feasibility of the proposed method.

1 Introduction

Constant-Current Constant-Voltage (CC-CV) strategy is the normal charging method for lithium-ion batteries due to the simple implementation. To improve batteries' performances and health, the pulsed current charging method was proposed [1]. Pulsed current provides a rest-time for batteries to fully complete the internal chemical reactions, which can suppress the increase of resistance, thereby extending battery lifetime [2]. Pulsed current can increase 100 life cycles at 23 ℃, 12 kHz, and 50% duty cycle when compared with CC-CV charging method [3]. In [4], the authors tested the battery using pulsed current at 0.05 Hz, 50% duty cycle, 1 C-rate charging, and 1.25 C-rate discharging, which illustrated that the lifetime of the battery can be extended about 20% when compared with CC-CV charging strategy. In [5], the capacity of the Lithium-Sulfur battery is recovered more than 20% when compared to that obtained during CC discharge.

For the implemental method of the pulsed current, the breaking switch is one of the possible methods. In [6], two back to back PMOS power transistors are applied as the main switches to implement the control of pulsed current. For the large battery pack, such as electric vehicles, the bidirectional dc/dc converter is used to implement the pulsed current [7]. But both of the methods mentioned above can only be used in charging periods due to discontinuous current through the dc-link.

Battery management systems (BMSs) play a critical role in ensuring the safe and reliable operation of Lithium-ion batteries. Smart battery is a potential trend for BMSs technology due to its high flexibility, scalability, and fault tolerance [8]. In a smart battery, each battery cell has a local controller, which can measure the voltage and current, supervise the temperature, and estimate the states of the local cell. Furthermore, the local controller can communicate with the master controller, which can take decisions at the system level, such as balancing operation.

In this paper, the author proposes a new method to implement the pulsed current using Phase-Shift Modulation (PSM) in the proposed Wireless Smart Battery Management System (WSBMS). Firstly, the architecture and the operation modes of the bypass device in the smart battery are introduced. Then, the working principle of the PSM is provided. In order to verify the proposed method, the simulation and experiment results are presented. Conclusions are drawn in the last part of the paper.

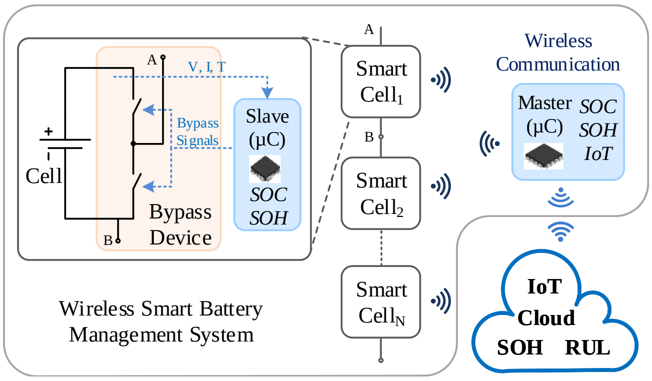

Fig. 1: Architecture of the proposed WSBMS.

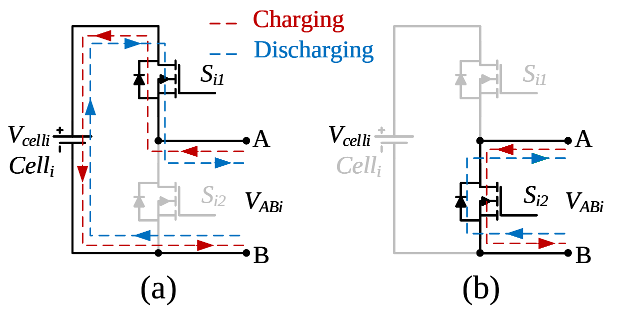

Fig. 2: Operation modes of the bypass device: (a) insert mode and (b) bypass mode.

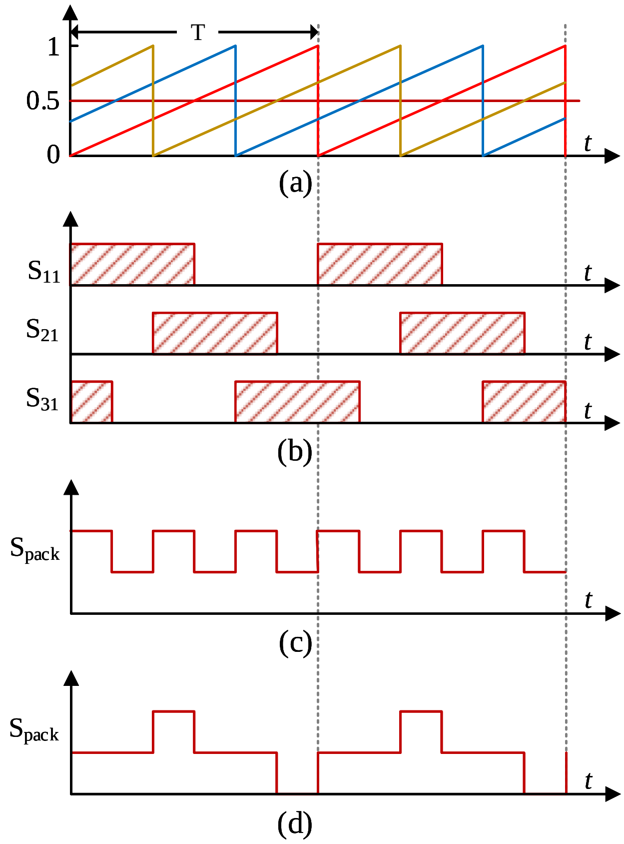

Fig. 3: Synchronized PSM for three smart cells: (a) carrier waves and the reference wave, (b) drive signals for each cell, (c) the total drive signals for the battery pack when all cells are inserted, and (d) the total drive signals for the battery pack when one cell is bypassed permanently.

2 Wireless Smart Battery Management System

2.1 Architecture of the WSBMS

The smart battery can be seen as a cell-level BMS where each of the battery cells have an independent manager. WSBMS is the smart battery based on wireless communication, as shown in Fig. 1. Wireless communication applied in the system can reduce wiring clutter and decrease the weight and size of the entire battery system. Each smart cell has its controller that integrates voltage and current sensors, temperature monitor, cloud communication (ToT) gateway, and the bypass device. The smart cell can estimate the state-of-charge (SOC) and the state-of-health (SOH) as well as predict remaining useful lifetime (RUL) of the local cell. The master controller is needed in WSBMS to make the decision at the system level. In the proposed WSBMS, each slave can exchange the information and work together with the master via wireless communication. There is no requirement of communication between any two smart cells due to the master-slave mode.

2.2 Bypass Device

Each battery cell is connected to the battery pack via a bypass device. The bypass device is a half-bridge circuit, which can bypass and insert the corresponding cell during both the charging and discharging processes. Four operation modes are presented in Fig. 2.

3 Phase-shift Modulation in Smart Battery

Each battery cell is connected to the battery pack via the bypass device, and also has a local manager to control the cell's operation state. Due to this distributed management, the local controller can generate the pulse signals to the bypass device, thus the cell can be charged/discharged by the pulsed current. In the following part, the

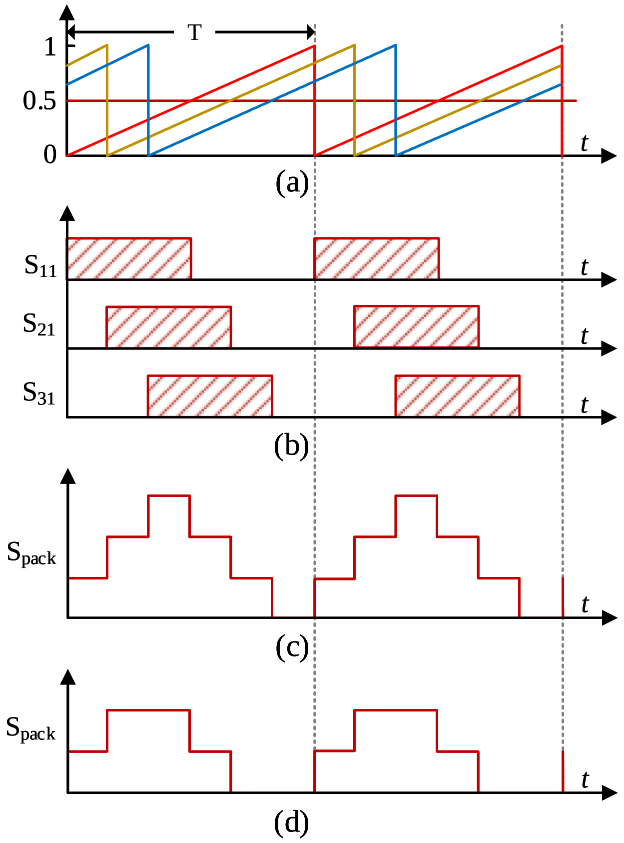

Fig. 4: One condition of unsynchronized PSM for three smart cells: (a) carrier waves and the reference wave, (b) drive signals for each cell, (c) the total drive signals for the battery pack when all cells are inserted, and (d) the total drive signals for the battery pack when one cell is bypassed permanently.

synchronized PSM and unsynchronized PSM for three battery cells are analyzed.

3.1 Synchronized PSM

For the synchronized PSM, the phase shift of each battery cell is T/N, where N is the number of battery cells and T is the carrier period. The phase-shift control method and the corresponding drive signals for three battery cells are shown in Figs. 3 (a) and (b), respectively. Fig. 3 (c) shows the total inserted signals of the entire battery pack when all cells are connected to the battery pack. If one cell is broken, this cell will be bypassed permanently without any changes in the architecture of the smart battery. Fig. 3 (d) shows that the total inserted signals of the entire battery pack when one cell is bypassed for a long period.

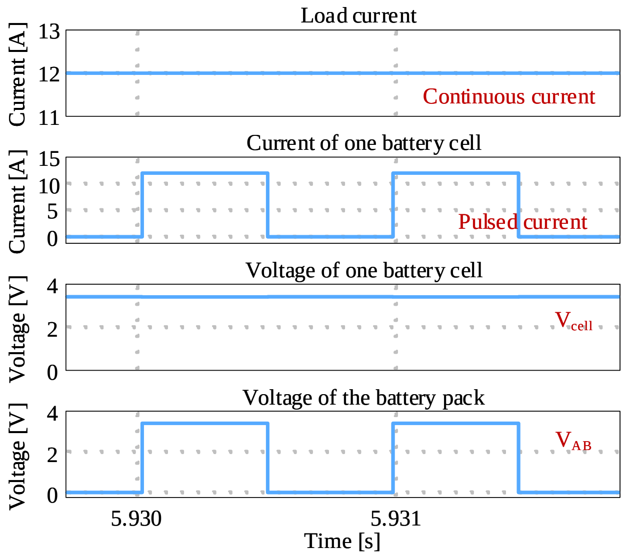

Fig. 5: Simulation results of synchronized PSM.

3.2 Unsynchronized PSM

For the unsynchronized PSM, the carrier wave of each battery cell can generate at any time. Fig. 4 shows one condition of the unsynchronized PSM for three battery cells. The phase-shift control method and the corresponding drive signals for three battery cells are shown in Figs. 4 (a) and (b). Figs. 4 (c) and (d) present the condition of all cells inserted and one cell bypassed for a long period, respectively.

4 Simulation and Experimental Results

Simulation and experimental results are provided in this section. For the simulation and experiment, the frequency of the carrier wave is 1 kHz, and the reference is 0.5. Thus, the pulsed current is operated at 1 kHz and 50% duty cycle. The simulation verified that the pulsed current can be realized by synchronized PSM. The experiment results verified that the pulsed current can be implemented using unsynchronized PSM in the proposed WSBMS. All the verification cases are performed during the discharging process. For the charging process, similar results can be obtained.

4.1 Simulation Results

The simulation results with five battery cells are provided for theoretical verification in PLECS, as

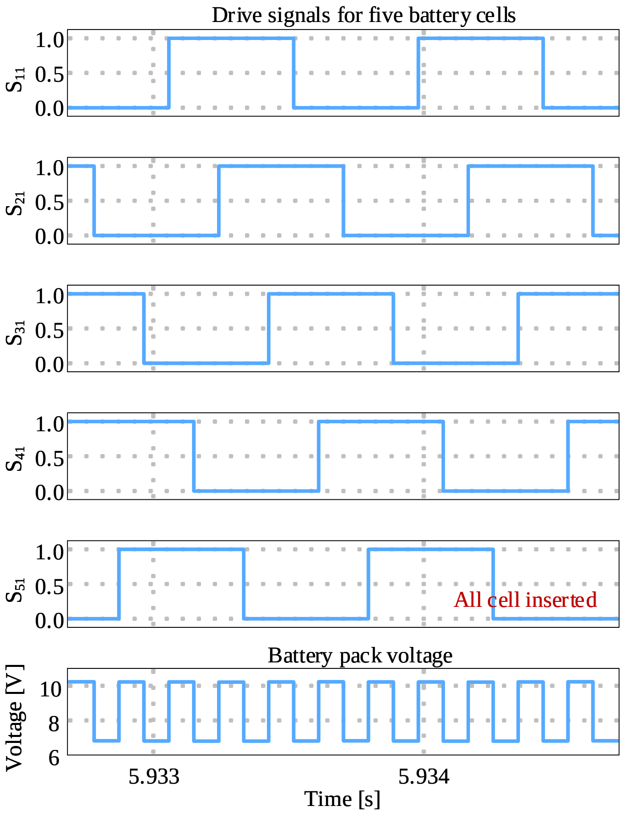

Fig. 6: Simulation results of synchronized PSM for five battery cells when all cells are inserted into the battery pack.

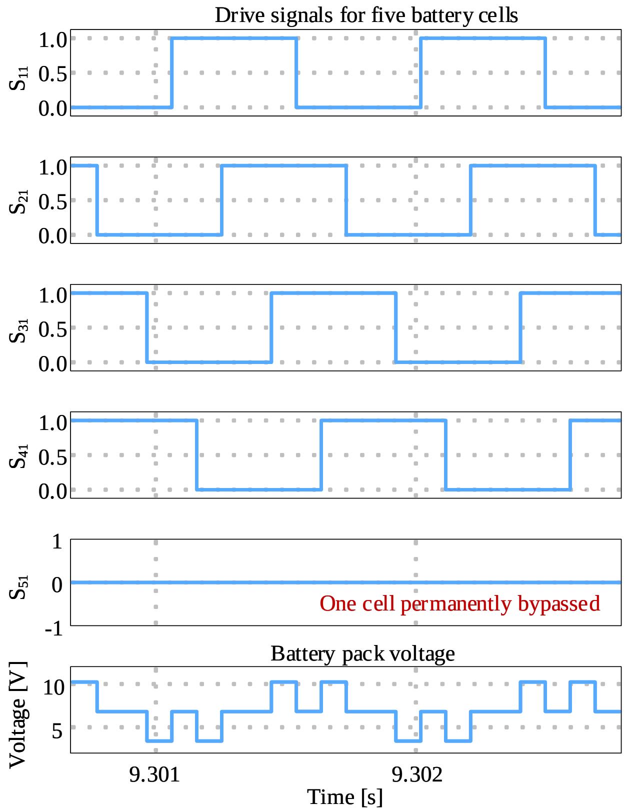

Fig. 7: Simulation results of synchronized PSM for five battery cells when one cell is bypassed permanently.

shown in Figs. 5-7. In Fig. 5, the load current maintains a continuous operating state, while the current through each battery cell is pulsed, where V_{cell} is the voltage of one battery cell, and V_{AB}, is the voltage of one cell module. Fig. 6 and Fig. 7 presents the simulation results when considering the condition of all cells that are connected to the battery pack and the condition of one cell bypassed for a long time. The voltage of the battery pack is not constant. However, this will not be an issue in a battery pack with large numbers of battery cells connected in series, because one permanently bypassed cell can only bring a slight voltage drop.

4.2 Experimental Results

An experimental prototype of the WSBMS is built in laboratory, as shown in Fig. 8. The slave is implemented on a TI Simplelink™ Wi-Fi® CC3220MOD controller, which provides wireless functionality at reasonable costs and has low energy consumption. The master controller is implemented on a Krtkl Snickerdoodle board driven by Zynq® processor 7020 and the wireless functionality is enabled with a certified WiLinkTM 8 module from TI - WL18DBMOD. There is no need for extra hardware to generate pulsed current, while the microcontroller of each slave has counters that can be used to implement phase shift modulation. The battery is replaced by battery cell simulators, and three channels of the cell simulators are used in the system to verify the proposed method.

In this paper, the current flowing out of the battery cell is defined as a positive direction. The battery cell is discharged by a 1-A load current. The current through each cell is pulsed, as shown in Fig. 9 (b). When the cell is inserted into the battery pack, the voltage of one cell module is the same as the voltage of the battery cell. When the battery cell is bypassed, the voltage of the cell module is zero. Fig. 10 shows the drive signals for three smart cells when all cells are connected to the battery pack and operated with the pulsed current. If one cell is bypassed permanently or during a long time, there are only

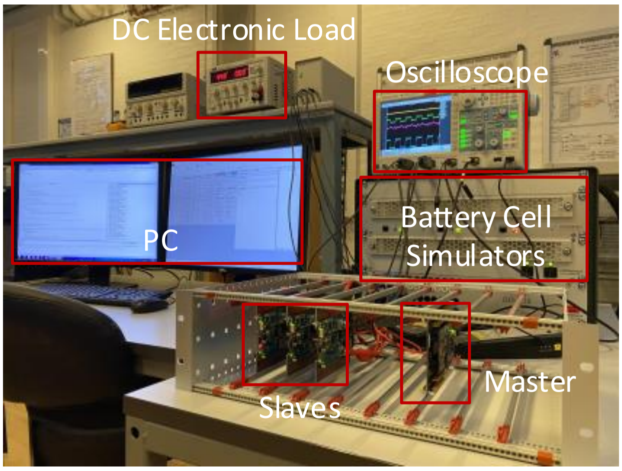

Fig. 8: Experiment setup of WSBMS.

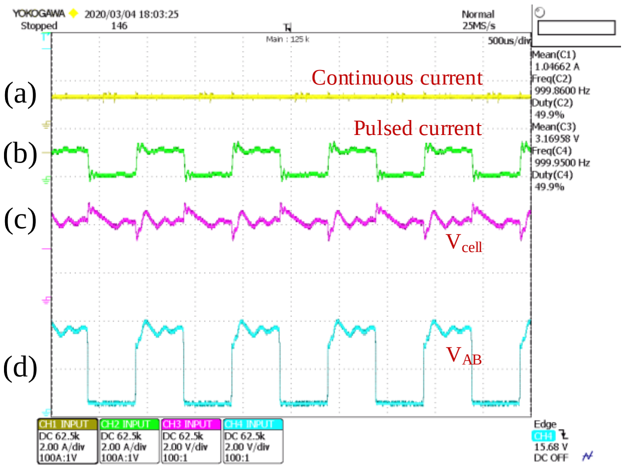

Fig. 9: Experimental results of unsynchronized PSM: (a) load current, (b) the current of one battery cell, (c) the voltage of one battery cell, and (d) the voltage of one cell module.

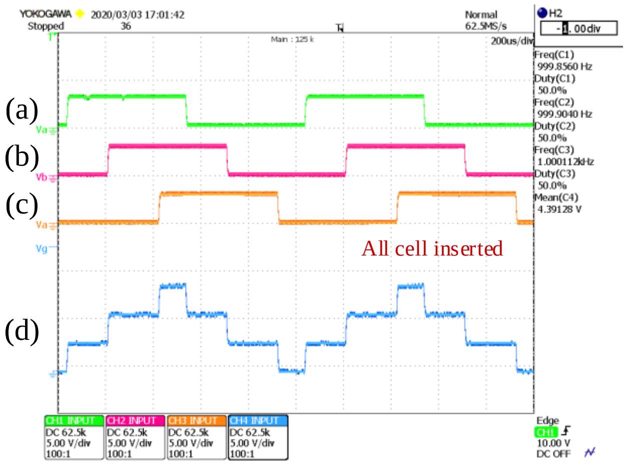

Fig. 10: Drive signals when all cells are inserted into the battery pack: (a)-(c) are drive signals for corresponding cells, and (d) is the drive signal for the entire battery pack.

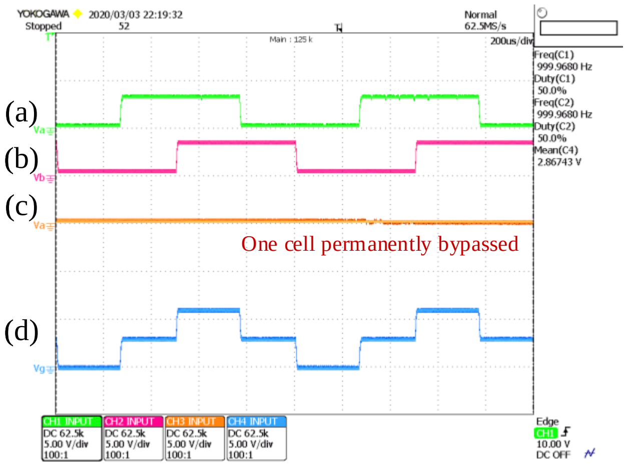

Fig. 11: Drive signals when one cell is bypassed permanently: (a)-(c) are drive signals for corresponding cells, and (d) is the drive signal for the entire battery pack.

two battery cells discharging by pulsed current, as shown in Fig. 11. This paper only provides one operating condition with unsynchronized PSM. Actually, during the entire discharging process, the working phases of the three cells are dynamically changed due to the out of synchronized of wireless communication. Therefore, the synchronized PSM to generate pulsed current can also be implemented in WSBMS. According to the experiment results, the voltage of the battery pack is zero in some time interval, because the paper only focuses on the pulsed-current implementation, thus only three smart cells are introduced to verify the proposed method. If there are more smart cells connected in series in the battery pack, this will not be a problem, which has been mentioned in section 4.1.

5 Conclusion

This paper proposes a pulse-current implementation using PSM in a smart battery. Every battery cell has an independent controller, which can generate the pulse drive signals to control the bypass circuit. Due to the benefit of the Smart Battery's architecture, each battery cell can be operated in pulsed current during charging and discharging processes. Due to no direct connection between two cells, the current through the entire battery pack is continuous. The simulation and experimental results verify that the proposed method can be implemented in the proposed WSBMS.

References

[1] J. Li, E. Murphy, J. Winnick, and P. A. Kohl, “The effects of pulse charging on cycling characteristics of commercial lithium-ion batteries,” *Journal of Power Sources*, vol. 102, no. 1-2, pp. 302–309, 2001.

[2] J. M. Amanor-Boadu, M. A. Abouzied, and E. Sánchez-Sinencio, “An efficient and fast Li-ion battery charging system using energy harvesting or conventional sources,” *IEEE Transactions on Industrial Electronics*, vol. 65, no. 9, pp. 7383–7394, 2018.

[3] J. Amanor-Boadu, A Guiseppi-Elie, and E Sánchez-Sinencio, “The impact of pulse charging parameters on the life cycle of lithium-ion polymer batteries,” *Energies*, vol. 11, no. 8, p. 2162, 2018.

[4] M. Alimardani, “A NEW APPROACH TO IMPROVE LITHIUM-ION BATTERY LIFETIME IN A RENEWABLE HOME ENERGY STORAGE SYSTEM,” PhD thesis, 2018.

[5] V. Knap, T. Zhang, D. I. Stroe, E. Schaltz, R. Teodorescu, and K. Propp, “Significance of the Capacity Recovery Effect in Pouch Lithium-Sulfur Battery Cells,” *ECS Transactions*, vol. 74, no. 1, pp. 95–100, 2016.

[6] J. Amanor-Boadu, E. Sanchez-Sinencio, and M. W. Asmah, “A universal fast battery charging and management solution for stand-alone solar photovoltaic home systems in sub-saharan africa,” in *2017 IEEE PES PowerAfrica*, IEEE, 2017, pp. 174–179.

[7] B. Arabsalmanabadi, N. Tashakor, A. Javadi, and K. Al-Haddad, “Charging techniques in lithium-ion battery charger: Review and new solution,” in *IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society*, IEEE, 2018, pp. 5731–5738.

[8] M. Ricco, J. Meng, T. Gherman, G. Grandi, and R. Teodorescu, “Smart Battery Pack for Electric Vehicles Based on Active Balancing with Wireless Communication Feedback,” *Energies*, vol. 12, no. 20, p. 3862, 2019.